Renewable and Sustainable Energy Reviews 40 (2014) 1126–1132

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Feed-in tariff promotion and innovative measures for renewable electricity: Taiwan case analysis

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ARTICLE INFO

Article history:
Received 27 June 2013
Received in revised form
24 July 2014
Accepted 6 August 2014

Keywords:
Feed-in tariff
Renewable electricity
Promotion regulation
Case study

ABSTRACT

Taiwan, located in a subtropical area, is a high energy-importing nation with approximately 98% of our energy supplied by imported fuels since 2000. In this regard, renewable electricity systems from its richness of solar radiation and strong monsoon are thus becoming attractive due to the energy, economic, and environmental policies for pursuing clean electricity supply, sustainable development and greenhouse gases emission mitigation in Taiwan. The objective of this paper was to present an analysis of profitable promotion and innovative measures for renewable electricity in Taiwan because the photovoltaic (PV) power and wind power systems have rapidly increased the total installed capacity from 2.7 MW in 2000 to 1006.2 MW in 2013. The description in the paper was thus summarized on an analysis of renewable electricity supply since 2000 and its future goals up to 2030, and then centered on the new promotion legislation (i.e., Renewable Energy Development Act) in the measures of feed-in tariff (FIT) and tax/subsidy incentives. Current subsidiary and innovative programs to promote the development of renewable electricity technologies, including roof-type PV power, off-shore wind power and biogas-to-power, were also described. Due to its innovation promotion for renewable energy exploitation in recent years, Pingtung County, located in the southernmost of Taiwan, was introduced as a case study. Finally, some recommendations for promote renewable electricity development were addressed in the paper.

Contents

1. Introduction

Taiwan has a dense population (total area: 36,200 km^2; population: 23,300,000 people; population density: 640 people/km^2) but limited fossil resources with high dependence on imported

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http://dx.doi.org/10.1016/j.rser.2014.08.019
1364-0321/

energy (about 98%). However, this country is located in a subtropical area with the richness of solar radiation and strong monsoon, implying that the island has a high potential for renewable energy development. In this regard, renewable energy sources in Taiwan will focus on off-shore wind power and solar energy like photovoltaic (PV) power. For example, it has been estimated that an enormous wind resource of more than 15 GW can be harvested in Taiwan. To accelerate the development of wind power industry, the government plans to shift the wind energy from onshore to offshore systems, and set up more than 1000 wind turbines by 2030. The accumulated capacity of wind will thus reach 4200 MW. Moreover, the current installed capacities of PV power and wind power in 2013 amounted to 392.0 MW and 614.2 MW, respectively [1]. However, the domestic energy consumption reached a total of 111.92 million kiloliters of oil equivalent (KLOE) in 2011, in contrast to 53.25 and 90.91 million KLOE in 1991 and 2001, respectively [1]. On average, the annual growth rate is about 3.8% during the period. Approximately in parallel with the energy consumption per capita, the electricity consumption and carbon dioxide (CO_2) emissions from the energy consumption remarkably increased from 4566.3 kW h and 5.7 MT per capita in 1991 to 10,494.7 kW h and 10.8 MT per capita in 2011. In recent years, the environmental issues such as global warming and sustainable development are consecutively arousing the concern of the public in response to the Kyoto Protocol adopted in December 1997 and coming into effect in February 2005. Regarding the public attitude toward renewable energy in Taiwan, for example, nearly 70% of people supported to replace nuclear energy with renewable energy based on the survey by the Public Opinion Research Center of Shih Hsin University. This survey was made targeting the people in the greater Taipei region during the first half of November in 2009, with 517 analyzable questionnaires, 95% confidence level, and error rate 4.5% [2]. Therefore, the energy strategies and policies for promoting energy saving and renewable energy in Taiwan have actively provided some environmental, financial, and economic incentives to pursue the energy sustainability during the period [3,4].

In 2008, the Executive Yuan of Taiwan issued the "Framework for Sustainable Energy Policy", which aimed at creating a new low-carbon economy and low-carbon society that balances economic development against environmental protection and energy security under the principles of "high efficiency", "high value-added", "low emission", and "low dependence (on foreign fuel sources)". In this regard, the policy for clean energy development is to pursue the following targets:

- Reducing nationwide CO_2 emissions by developing clean energy, so that total emissions could return to its 2008 level between 2016 and 2020, and further reduced to the 2000 level in 2025.
- The clean energy development is to achieve the share of zero carbon renewable energy in electricity generation system up to 8% in 2025.

To be in accordance with the Framework, the Legislative Yuan of Taiwan further passed the Renewable Energy Development Act in June 2009. The Act is comprised of 23 articles, and is enacted to promote the utilization of renewable energy, increase energy diversification, improve environment quality, energize the industrial development and drive the national sustainability. More significantly, the policies for developing renewable electricity supply prescribed by the Act include the feed-in tariff (FIT), subsidy for purchasing renewable generation equipment, and tax incentives. On the other hand, there have been a number of funds-supporting projects on renewable energy education in Taiwan in recent years. For example, the interdisciplinary green energy technology education program under the funding support by the Advisory Office of Ministry of Education (MOE, Taiwan) was a four-year project starting from 2007 to 2010, and designing for undergraduates of the College of Engineering. It aims at developing core and professional courses by integrating interdepartmental knowledge. Also, Taiwan has implemented 5-year (2009–2013) "National Science Technology Program: Energy Human Resource Development" project, which coordinated relevant government agencies, including MOE, National Science Council (NSC) and Environmental Protection Administration (EPA) to promote climate change and energy education.

Currently, the FIT scheme is the most popular procurement option for the development of renewable electricity such as wind power and PV power [5,6]. Many countries (e.g., Germany, UK, Spain, Italy, Japan, and France), or the states/provinces of countries (e.g., USA, Australia, and Canada) have established the FIT regime. Due to the geographical region and local energy security, the FIT policy has various dimensions and coverage in different countries. Furthermore, the FIT rates for the same renewable electricity source differ across these countries [6]. For example, the highest FIT payment belongs to the Victoria state of Australia, where the payment for wind, hydro, biomass, and solar energy was fixed at 0.8 US$/kW-h in 2013. By contrast, Argentina received the lowest FIT payment at almost US$0.001 for electricity generated from biogas, biomass, and wind power. In brief, it is a policy mechanism designed to accelerate investment in a variety of renewable electricity technologies and also offer long-term contracts to renewable electricity suppliers. The goal of FIT is to offer cost-based compensation to renewable power producers, providing the profitable price help finance renewable electricity investments. The FIT rates are typically based on the installation cost for each technology and other factors, including operation and maintenance cost and capital recovery factor. For example, wind power system is awarded a lower per-kW h price, while solar photovoltaic (PV) power is offered a higher price because of its higher installation cost. In addition, the FIT policy often includes "tariff decline", reflecting a decreasing trend in the costs of renewable electricity technologies, especially in PV power system. In other words, the FIT rate may be no longer a constant subsidy price within one year, but could decline over time.

According to the official survey on the renewable electricity since 2000 [1], the total installed capacities of PV power and wind power remarkably increased from 0.1 MW and 2.6 MW in 2000 to 392.0 MW and 614.2 MW in 2013, respectively. Because of the considerable progress in the renewable electricity development, the objectives of this paper will present a comprehensive analysis of the FIT promotion and innovative measures for renewable power system in Taiwan. The main subjects covered in this paper were described in the following key elements:

Current status of renewable electricity supply and its future goals.
Central regulations for promoting renewable electricity.
Taiwan's FIT evolution and its policy.
Current innovation promotion and measures for renewable electricity.
Case study of Pingtung County.

2. Current status of renewable electricity supply and its future goals

2.1. Current status of renewable electricity supply

In response to the Kyoto Protocol adopted in December 1997, promoting the renewable energy and thus supplying renewable electricity have been considered as one of the most

environment-friendly strategies for the purpose of getting an equal focus on economic development, energy security, and environmental protection. In January 2002, the Executive Yuan of Taiwan adopted the "Renewable Energy Development Plan". The Council for Economic Planning and Development (CEPD) was in charge of coordinating the efforts from central competent authorities in promoting renewable energy. The important measures and promotions in the Plan were summarized in the previous study [3].

By December of 2013, the total installed capacity of renewable electricity in Taiwan reached around 3700 MW. Tables 1 and 2 listed the statistical data on the installation capacity of renewable electricity and its supply during the period of 2000–2013, respectively. Currently, the renewable electricity sources in Taiwan mainly include conventional hydropower, biomass-to-power, PV power and on-shore wind power. Herein, the biomass includes municipal solid waste (MSW), biogas and agricultural and industrial residues such as paper mill waste, bagasse and rice straw. Obviously, the total installed capacity of renewable electricity in Taiwan significantly increased from 2262.5 MW in 2000 to 3828.0 MW in 2013, which was on an annual average growth rate of 4.1%. According to the data in Tables 1 and 2, the structure of renewable electricity in Taiwan has changed during the period as follows:

1. The total installed capacity of hydropower showed slight increase from 1820.0 MW in 2000 to 2081.3 MW in 2012 due to the difficulty of the large-scale hydropower exploitation in Taiwan. In order to mitigate the impact on watershed's environment, the small hydropower facilities with the total installed capacity of about 150 MW have been mainly developed in recent years.
2. The total installed capacity of biomass-to-power, including MSW-to-power, biogas-to-power and other biomass-to-power sources, also indicated slight increase from 439.8 MW in 2000 to 740.4 MW in 2013, which was primarily based on 24 operational large MSW incineration plants (about 625 MW). It should be noted that the construction of MSW incineration plant has been ceased since 2002 owing to the policy promotion for recycling the components in MSW (e.g., paper, plastics) as valuable materials [7], causing the limited increase from biomass-to-power. With respect to the renewable electricity supply from biomass-to-power systems (Table 2), it can be found that the green power showed in parallel with its total installed capacity, increasing from 1832,447 MG h in 2000 to the maximal generation (i.e., 3623,292 MG h) in 2007. Thereafter, the renewable electricity supply had gradually decreased from 3623,292 MG h in 2007 to 3405,130 MG h in 2013 due to the steady decline in the supply of biomass sources, especially in biogas.
3. According to the official statistics on the status of renewable electricity supply and its installed capacity, the productivities of renewable energy systems, including biomass-to-power, PV power and wind power operation will be relatively low. For example, the operation status of 24 large-scale MSW incineration plants with design capacity of over 300 t/day in Taiwan showed that the overall energy efficiencies were about 16% in the past decade (2002–2012) [8]. This meant that a majority of produced heat was discharged into the atmosphere without efficient recovery for power generation. On the other hand, the performance ratio (PR), which was defined as the ratio of PV energy actually used to the energy theoretically available, has been used to assess the PV system performance [9]. It was indicated that the average PR of Taiwan's PV systems was about 0.74. This value was similar with that of other countries like Japan. Regarding the performance of wind power in Taiwan, the capacity factor has been used to assess its productivity. It is defined as the ratio of a turbine's actual output at a given location to the amount of power it would produce if it were to run at full load throughout the year (about 2500 h on Taiwan's west coast). The average capacity factor of Taiwan's wind turbines runs about 29% because the turbines can generate power in winds of less than 10 m/s [10]. This value was slightly higher than that (i.e., 24.9%) of wind farm in India [11].
4. To promote the development and application of renewable electricity from physically natural resources, the government of Taiwan, under the planning and execution of the central competent authority (i.e., Ministry of Economic Affairs), has implemented many financial measures for subsidizing the solar photovoltaic (PV) energy and wind power since 2000 [3,12]. As a result, the total installed capacities of PV power and wind power remarkably increased from 0.1 MW and 2.6 MW in 2000 to 392.0 MW and 614.2 MW in 2013, respectively. On average, annual growth rates of PV power and wind power in terms of installed capacity during the period are about 80.9% and 52.2%, respectively. In this connection, the total amounts of renewable electricity supply from PV power and wind power significantly increased from 120 MW h and 1383 MW h in 2000 to 337,854 MW h and 1574,322 MW h in 2013, respectively. However, the increase rate from on-shore wind power is on the

Table 1
Statistics on installation capacity of renewable electricity in Taiwan since 2000[a].

Year	Hydropower	Photovoltaic power	Wind power	Biomass-to-power [b]	Sum
2000	1820.0	0.1	2.6	439.8	2262.5
2001	1820.0	0.2	5.0	618.2	2443.4
2002	1908.8	0.3	8.5	603.0	2520.6
2003	1908.8	0.5	8.5	615.5	2533.3
2004	1909.7	0.6	8.5	644.9	2563.7
2005	1909.7	1.0	23.9	672.9	2607.5
2006	1909.7	1.4	102.0	726.3	2739.4
2007	1921.2	2.4	186.0	739.3	2848.9
2008	1937.9	5.6	250.4	739.3	2932.2
2009	1936.9	9.5	374.3	739.3	3060.0
2010	1977.4	22.0	475.9	739.3	3214.6
2011	2040.7	117.9	522.7	735.7	3417.0
2012	2081.3	222.4	571.0	740.4	3615.1
2013	2081.3	392.0	614.2	740.4	3828.0

[a] *Source*: [1]; unit: Megawatt (MW).
[b] The reuse of municipal solid waste (MSW), waste heat, bagasse, black liquor and biogas as biomass for generating electricity.

Table 2
Statistics on renewable electricity supply in Taiwan since 2000[a].

Year	Photovoltaic power	Wind power	Biomass-to-power [b]
2000	120	1,383	1832,447
2001	264	12,229	2348,937
2002	348	15,880	2928,853
2003	461	23,762	3009,198
2004	584	25,253	3187,634
2005	960	91,300	3189,376
2006	1,457	276,075	3287,633
2007	2,180	439,535	3623,292
2008	4,569	588,265	3420,783
2009	9,211	786,635	3401,663
2010	25,587	1026,338	3575,597
2011	70,266	1492,677	3419,028
2012	173,078	1413,451	3363,143
2013	337,854	1574,322	3405,130

[a] *Source*: [1]; unit: Megawatt-hour (MW h).
[b] The reuse of municipal solid waste (MSW), waste heat, bagasse, black liquor and biogas as biomass for generating electricity.

decreasing trend because the on-shore sites for developing wind power along the west coast of Taiwan rapidly approached to a saturated market of being already installed.

2.2. National goals for renewable electricity supply

On June 12, 2009, the Renewable Energy Development Act, which was aimed to promote of renewable energy, boost energy diversification, and help mitigate greenhouse gases emissions, was passed by the Legislature Yuan, Taiwan's law-making body. In July 2009, the Taiwanese government was taking the lead in promoting an energy-saving and carbon-reduction culture on the island with the approval of "Framework for Sustainable Energy Policy". The Framework aimed at creating a new low-carbon economy that balances economic development, environmental protection and energy security under the principles of sticking to "high efficiency", "high value-added", "low emission", and "low dependency (on foreign fuel sources)". In the Framework, it was intended for attaining a definite goal: cutting annually CO_2 emission to the levels of the year 2008 during the period of 2016–2020, and curtailing annual emission of CO_2 to the levels of the year 2000 in 2025.

Based on the above-mentioned background, the central competent authority in Taiwan has set up national goals for promoting renewable electricity in 2012. Table 3 listed the national goals for renewable electricity in terms of accumulative installed capacity, indicating that Taiwan will place emphasis on off-shore wind power and PV power, and also promote other renewable electricity sources in the near future. Making a comparison between the current installation capacity in 2010 (i.e., 3300 MW) and the goal in 2025 (i.e., 9952 MW), it showed a considerable increase in renewable electricity supply of 200% over the next 15 years (2010–2025). The goals are in accordance with the regulatory order set by the Renewable Energy Development Act, which will be described in the following section.

3. Central regulations for promoting renewable electricity

In Taiwan, the central regulations for promoting renewable electricity are in accordance with the Renewable Energy Development Act, passed on June 2009. This law is enacted to promote renewable energy, increase energy diversification, improve environment quality, empower the industry and drive the national sustainable development. In this respect, the renewable energy refers to solar energy, biomass energy, geothermal energy, ocean energy, wind power, and non-pumped-storage hydropower. The energy generated from either direct or processed domestic general waste (i.e., municipal solid waste) and general industrial waste, or other sustainable energy affirmed by the central competent authority are also blanketed into the categories of renewable energy. According to the newly Act, the important features concerning the renewable power generation (i.e., renewable electricity) equipment were briefly described as follows:

1. In the promotion of renewable electricity equipment, the central competent authority shall consider the climate and environment in Taiwan, characteristics of electricity demand, the economic benefits, and technological development for each type of renewable energy, and other factors.
2. The central competent authority may consider domestic renewable energy development potential and its influence to domestic economy and power supply stability, to set promotion targets and the percentage of each category for every two years within 20 years from the enactment of this Act. The subsidy capacity for the renewable electricity equipment, which refers to the electricity equipment that is not non-river-type hydropower type or direct waste combustion type, is the total capacity between 6500 MW and 10,000 MW.
3. The central competent authority shall organize the Commission to decide the feed-in tariffs (FIT) and the calculation formula for the power generated by the renewable electricity equipment every year. The aforementioned tariffs calculating formula shall be determined according to the average installation cost, operating life, operation and maintenance cost, annual electricity generation and relevant renewable electricity equipment factors separately for each category of the renewable energy.
4. In this regard, promotion rewards shall be given for a specific period of time by the central competent authority to the renewable electricity equipment with development potential at the early stage of technological development.

On a previous green policy, the Legislative Yuan of the Taiwan government passed the Government Procurement Law in 1997, in which the Article 96 authorizes the government to execute green procurement in the official organizations (central/local government authorities), including government offices, public schools and government-owned enterprises. As a consequence, the related regulation ("Regulations for the Priority Procurement of Environmentally Preferable Products by the Government Agencies") was promulgated on May 26, 1999. These green-mark products cover the energy-saving appliances and the items for producing renewable electricity from PV systems.

Table 3
Goals for renewable electricity in terms of accumulative installed capacity in Taiwan.

Category of renewable electricity	Accumulative installed capacity (MW)				
	2010	2015	2020	2025	2030
On-shore wind power	476	866	1200	1200	1200
Off-shore wind power	0	15	600	1800	3,000
Hydropower	1977	2052	2112	2502	2,502
Photovoltaic power	22	420	1020	2500	3,100
Geothermal power	0	4	66	150	200
Biogas-to-power	25	29	29	31	31
Waste-to-power	800	848	925	1369	1,369
Ocean power	0	1	30	200	600
Fuel cell	0	7	60	200	500
Sum	3300	4242	6042	9952	12,502

4. Taiwan's FIT evolution and its policy

In the past decade, the feed-in tariff (FIT), which is a mechanism used to encourage renewable electricity systems (e.g., roof-top solar PV system), has been the most popular procurement policy worldwide compared to other procurement options such as renewable portfolio standard and tax incentives [5]. Historically, FIT has been associated with a German model in which the central government mandates that utilities (electricity suppliers) enter into long-term binding contracts with renewable electricity generators at specified rates, typically well above the retail price of electricity. In brief, the FIT scheme provides a guaranteed rate ($ per kW h) that the energy (electricity) suppliers might pay them money if they generate the renewable electricity. Also, this procurement guarantee is usually coupled with access to the local electricity grid system. The tariff often varies depending on the scale size of the renewable electricity system and its technology installed, when the adopted technology was installed, who put the technology in place, and other specific considerations. Herein, the renewable energy system should be installed by the certified firms.

Prior to the Renewable Energy Development Act enacted in 2009, the central competent authority in Taiwan has adopted subsidiary incentives to promote renewable energy development. However, accelerating the sustainable energy in a time-table way is the vital aim of the Act, which mandates the FIT policy for renewable electricity generated from specified sources, especially in solar PV power and wind power. As described above, the FIT policy prescribed by the Act contains four implementation elements, including subsidy target for renewable electricity, FIT rate setting mechanism, government procurement by state-owned power company, and mandatory grid connection. In Taiwan, the calculation formula of FIT for renewable electricity are based on the relative factors of generation equipment, including installation cost, operation and maintenance (O&M) cost, operating years, annual power generation, capital recovery factor, reasonable profit rate, and other factors such as inflation rate and insurance fee. Based on the levelized cost approach, the central competent authority announced the calculation formula for setting FIT rates in each year:

$$\text{FIT rate} = [(\text{IIC} \times \text{CRR}) + \text{AOMC}]/\text{AE}$$

$$\text{CRF} = [\text{ACCR} \times (1+\text{ACCR})^{\text{P}}]/[(1+\text{ACCR})^{\text{P}} - 1]$$

where IIC: initial installation cost

CRR: capital recovery factor
AOMC: annual operation and maintenance cost.
AE: annual electricity sold (kW h).
ACCR: average capital cost rate.
P: FIT period (year).

Table 4 listed the feed-in tariffs (FIT) for various categories of renewable electricity production in Taiwan effective in 2014. The FIT values for the years of 2010–2014 were also listed in Table 4 to see the substantial variations. Although the FIT rates for PV power systems indicated a gradual decline, the fixed rates still provided reasonable profits for investors. As of Oct. 2010, the Taiwan government received 847 applications that will increase renewable electricity capacity of 434 MW based on the preferred FIT [13], showing that the FIT mechanism in Taiwan was effective in its initial stage. Consistently, the installed capacity of PV system remarkably increased from 22 MW in 2010 to 392 MW in 2013. As illustrated in Table 4, several observations can be made as follows:

1. There are four scales for the roof-type PV systems with FIT rates ranging between NT$ 11.1190 (US$ 0.377; 1 US$≒29.5 NT$) and NT$ 12.9722/kW h (US$ 0.440/kW h) in 2010. Due to the rapidly decreasing cost of PV system, the FIT rate in 2014 has decreased by over 50% as compared with the rate in 2010. On the other hand, the constant yearly FIT rate is not appropriate because the cost-down of PV system is very dramatic within one year in recent years. In other words, the FIT rate for PV system effective in 2012 was no longer a constant subsidy price. There are two rates for the PV power systems completed before the periods of June 30 and December 31, respectively.
2. For wind power, the on-shore FIT rates have no significant change during the period of 2010–2014. By contrast, the off-shore FIT rate for wind power system has a significant increase around 33% over the years, reflecting on the policy promotion for the renewable electricity development in the Taiwan Strait.
3. The FIT rates for other renewable electricity sources except geothermal power also indicated an increasing change due to the cost variation and policy promotion. For example, the tariff of hydropower and biomass-to-power in 2010 is 2.0615 NTD (US$ 0.070)/kW h, showing an increase of 20.0–35.7% from 2013.

5. Current innovation promotion and measures for renewable electricity

5.1. Renewable electricity from photovoltaic power

Taiwan, which lies in a subtropical zone between 21°N and 25°N latitudes, provides the best solar irradiation for photovoltaic (PV) power systems installation. Under the government incentives in recent years, the central competent authority has subsidized the PV installation through the FIT policies and projects, such as Solar Community Project, Solar Top Project for Each County, Solar Campus Project, and Public Building Installation Project. Many PV systems

Table 4
Feed-in tariff (FIT) rates for renewable energy (RE) category in Taiwan.

RE category	Type	Scale (kW)	FIT (US$/kW-h)[a]				
			2010	2011	2012[d]	2013 [e]	2014
Photovoltaic power	Roof	1–10	0.379	0.350	0.321 (0.314)	0.285 (0.277)	0.243
		10–100	0.440	0.311	0.289 (0.282)	0.256 (0.248)	0.218
		100–500	0.440	0.299	0.277 (0.270)	0.241 (0.234)	0.205
		≥500	0.377	0.270	0.247 (0.244)	0.215 (0.203)	0.177
	Ground	≥1	–[b]	0.248	0.234 (0.229)	0.203 (0.191)	0.167
Wind power	On-shore	1–10	0.246	0.249	0.249	0.249	0.277
		≥10	0.081	0.089	0.088	0.089	0.089
	Off-shore	–	0.142	0.189	0.189	0.189	0.189
Hydropower [c]	–	–	0.070	0.074	0.079	0.084	0.085
Geothermal power	–	–	0.176	0.163	0.163	0.163	0.167
Biomass-to-power	Non-anaerobic	–	0.070	0.074	0.079	0.084	0.085
	Anaerobic				0.092	0.095	0.110
Waste-to-energy	–	–	0.071	0.091	0.096	0.096	0.096
Others	–	–	0.070	0.074	0.079	0.084	0.085

[a] The exchange rate of Taiwan's currency (i.e., New Taiwan Dollar, NTD) to USD is about 29.5 in 2012.
[b] In 2010, the FIT rates for photovoltaic power were not classified by the system type.
[c] Run-of-the-river hydropower (also called small hydropower).
[d] The rates only applied to the PV power system completed during the period from Jan. 1 to Jun. 30, 2012. By contrast, the rates in parentheses only applied to the PV power systems completed during the period from Jul. 1 to Dec. 31, 2012.
[e] The rates only applied to the PV power system completed during the period from Jan. 1 to Jun. 30, 2013. By contrast, the rates in parentheses only applied to the PV power systems completed during the period from Jul. 1 to Dec. 31, 2013.

have been installed in public buildings for demonstration purposes, for instance the Presidential Building, Legislation Yuan and Department offices. Moreover, the system was also widely installed in commercial buildings, public schools and remote areas in offshore islands and agricultural counties for its functions of energy education demonstration, land restoration and even capital gain by selling their surplus electricity to Taiwan Power Company (one of state-owned companies). Currently, under the central competent authority, subsidization thousands of PV systems have been set up, with a total installed capacity of 392.0 MW (Table 1), which generated electricity up to 337,854 MW h in 2013 (Table 2). Thus, it provides approximately 100,000 households for one-year consumption based on annual electricity consumption of 2500 kW h per family with 4 people.

To encourage solar PV installations in Taiwan, drive economic growth, facilitate the development of the solar PV industry, and also reach a goal for installation capacity of 3100 MW by 2030 (Table 3), the central competent authority has launched the "Million Solar Rooftop Program" on March 13, 2013. The program will adopt a PV-ESCO (Photovoltaic-Energy Service Company) model. Also, local governments at county and city level can apply for subsidies when the solar PV systems include 10 households and the total installed capacity reaches 50 kW in their respective jurisdictions. Local governments can earn NT$ 200,000 (≒ US$ 6800) in grants for each application that reaches 50 kW in capacity. The amount of subsidies will increase with installation capacities increased. Meanwhile, solar PV system installers can also receive subsidies for the costs incurred from connecting their PV power systems to the utility grid (such as connection impact analysis, connection examination, connection construction, grid reinforcement, connection subsidy, and electricity step-up projects). The maximum subsidy for each item in each case is NT$ 100,000 (≒ US$ 3400). There are three rounds of applications each year, on March 15, June 15, and September 15.

5.2. Renewable electricity from wind power

Taiwan has an enormous advantage in its excellent geographic location and abundant wind resources along the western, southern coasts and on off-shore islands [14]. Under the central competent authority funding support since 2000, the state-owned enterprise (i.e., Taiwan Power Co.) and private enterprises have heavily invested in the on-shore wind power plants under the policy supports, assistance incentives and economic considerations. As a result, the total installed capacity of wind power systems was on the increasing trend in the past decade, whose subsidization was approved of by 2013 was around 614 MW with over 250 sets of wind turbines built by the state-owned company and some private sectors. More significantly, the electric power generation from on-shore wind power systems increased from 1383 MW h in 2000 to 1574,322 MW h in 2013. The clean energy supply from wind power can provide enough electricity to about 600,000 households for one-year consumption.

In Taiwan the central competent authority has set a target of renewable energy contributing to over 15% of Taiwan's overall electricity generation by 2030, and wind power is expected to make up to 25% of that renewable energy contribution (Table 3). It is anticipated that, due to this commitment and the country's wind resources and manufacturing capabilities, Taiwan's wind power generation will grow to 3000 MW by 2030, and create a renowned wind energy industry. In order to foster the development of off-shore wind farms due to dense distribution in coastal areas, lower capital costs for building new wind turbines and meet the national goals for renewable electricity supply, the Executive Yuan has ratified the "The Program of First Stage of Offshore Wind Development" proposed by the central competent authority on July 3, 2012, which targets on developing 300 MW of offshore wind power in the first stage. According to the "The Incentive Program of Offshore Wind Power Demonstration System", in addition to the 50% incentive fees for the installation of demonstration units provided by the central competent authority, NT$ 2.5 hundred million (≒ US$ 8.5 million) will also be subsidized for the demonstration wind farm development. The Program will complete 4–6 demonstration units by 2015, and will commission 3 demonstration wind farms by 2020 with a total capacity of 300 MW or more. Moreover, the demonstration incentive program is a trial model of large scale offshore wind farm development. In the near future, offshore wind farms will be developed in zonal scales with 300 MW per year at deeper water area of the Taiwan Strait to gradually reach 3000 MW with 600 wind turbines by 2030.

5.3. Renewable electricity from biogas power

Anaerobic digestion of organic waste has been performed on many plants for several decades because it is considered to be a technically proven and commercially attractive process. The resulting biogas has many significant benefits, including the reduction of methane emissions from waste management, and the production of renewable electricity and heat, resulting in a reduction of odor and carbon dioxide (CO_2) [15]. In Taiwan, the anthropogenic methane sources from animal agriculture are mostly produced by the anaerobic decomposition of livestock (especially in swine) manure [16], thus providing the high potential for biogas production. In my previous study [17], the potential of methane generation from livestock manure management in Taiwan has been estimated to be at about 40,000 MT annually, indicating that the biogas (methane) from swine and dairy cattle is abundant. On the other hand, landfill gas (LFG) was also one of the most important biogas sources because it is derived from the anaerobic decomposition of biodegradable fraction (e.g., kitchen garbage) in the municipal solid waste (MSW) that is disposed of into sanitary landfills. However, it should be noted that the generation of LFG in Taiwan is on the decreasing trend due to the waste management policies for taking kitchen waste reuse and MSW incineration treatment over sanitary landfill in the past decade.

To further utilize the biogas power thus produced from a great variety of organic resources, the central competent authority recently announced "the Subsidiary Plan for Promotion Project on Biogas-based Power Generation System" on January 22, 2013. The aforesaid outline of the subsidiary plan can be carried out by the local government to subsidize the construction of an anaerobic waste or wastewater treatment plant to produce the purified biogas and also install a biogas-based power generation system. Furthermore, the installed capacity per application must range from 65 kW to 500 kW so as to meet the requirement for biogas-based power generation system. The maximum of subsidy per kW is NT$ 35,000 (≒ US$ 1200), and the total subsidy for installing biogas-based power generation system does not exceed half of its installation cost. The local government is also granted promotion fee for demonstration projects. Therefore, the application of a variety of biomass-based power generation can be stimulated by virtue of the cooperation between the central competent authority and local government.

6. Case study of Pingtung County

Pingtung County is a county in Southern Taiwan, which belongs to the tropical region. This agricultural County occupies about 2800 km^2 covering 33 towns and has a population of around 860 thousands. In the end of the year 2012, there are 31 cities/counties that have announced to win IBM Smarter Cities Challenge grants for 2013 [18]. Pingtung County is the only Taiwan municipality to make the final winner this year and was selected on the strength

of its renewable energy promotion plan, especially in the photovoltaic (PV) system installation.

Although Taiwan is geographically rich in renewable resources, it sometimes encounters catastrophic damages from natural disasters, causing the significant lose in the agricultural and aquacultural industries. For example, Typhoon Morakot, a record-breaking rain in 2009, made fish farms in the Pingtung County unable to operate, as well as destroying local wax apple orchards. To connect with the National Land Restoration Policy in Taiwan, the "Raise Water, Grow Electricity" plan was supported by the Pingtung County Government and aquacultural sector to install PV systems, which promoted by the central government under the profitable incentives of feed-in tariffs (FIT) since 2010 [4]. For example, the wholesale FIT for solar energy with a capacity of ranging from 10 kW to 500 kW was set at US$0.44 (i.e., NT$12.9722) per kilowatt hour (kW h) in 2010, as listed in Table 4. The originality of this plan was to use these abandoned farms and aquacultural ponds as sites for PV power generation facilities. The solar power generated by the PV stations will be sold back to the electricity grid system. As the farmers lacked the capital to set out on such a venture, the Pingtung County Government invited the PV industry involved, organized rental agreements with landowners, and secured investment from enterprises, asking them to cover the application and installation costs. In 2012, under the subsidization by the central and local governments, 4 sites of PV stations have been set up in the total area of 48.7 ha, with a total installed capacity of 25 MW.

7. Conclusions and recommendations

Since 2000, sustainable power generation in Taiwan remarkably increased in response to the trends of global warming mitigation and renewable electricity development. One of the significant milestones in the reform of the electricity industry in Taiwan could be said to have been implemented in 2009 when the central government promulgated the Renewable Energy Development Act. Under the authorization of the Act, the FIT scheme was adopted to encourage the deployment of renewable electricity systems for the purpose of selling their surplus electric power at a profitable rate to the local power company. During the period of 2000–2013, the renewable electricity from PV power and wind power systems in terms of total installed capacity in Taiwan have rapidly increased from 2.7 MW in 2000 to 1006.2 MW in 2013. However, the growth rate of renewable electricity systems in terms of total installed capacity seemed to show a steady increase since 2008, mainly due to the decreasing trend in domestic investments by the industrial and energy sectors. As a result, the central competent authority in Taiwan has adopted subsidiary programs starting from 2013 to promote the development of renewable electricity technologies, including roof-type PV power, off-shore wind power and biogas-to-power.

To encourage the investment in renewable electricity system as an emerging industry development and a measure for the reduction of greenhouse gases emissions, and also achieve the government goal (i.e., total installed capacity reached 9900 MW in 2025, as compared to 3300 MW in 2010), the following measures are recommended and enhanced:

Increasing the subsidies to install waste-to-power and biogas-to-power systems under the support of special funds (e.g., "Air Pollution Control Fee") because greenhouse gases have been listed as air pollutants under the authorization of Air Pollution Control Act.

Designing a reasonable and applied price for purchasing surplus electricity (i.e., net metering policy) to encourage the investment in the renewable electricity technologies because renewable energy development has been categorized as an emerging industry for promotion. Again, giving a payback period with 8 years or less based on the feasibility test to be preferential FIT price.

Demonstrating new renewable electricity technologies (e.g., micro-turbine, PV panel) appeared on the market for the purpose of broadening a wide variety of applications to agricultural, residential and commercial sectors.

Promoting the implementation of environmental accounting or green accounting, and combine "green" costs (e.g., carbon or energy tax) with the accounting system of enterprise or business. Also, establishing financial incentives to promote renewable energy systems, including business energy investment tax credit, preferential loans, and accelerated depreciation.

Deregulating the electric power industry in Taiwan by the amendments of Electricity Act to upgrade the operation (connection) performances of the existing grid systems because of the competitive pressure from new entrant generators.

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